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ENVIRONMENTAL EFFECTS OF DIKES AND REVETMENTS ON LARGE RIVERINE SYSTEMS

by

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Beginning in 1978, the Environmental and Water Quality Operational Studies (EWQOS) Work Units VA and VIIB were conducted by the Environmental Laboratory, US Army Engineer Waterways Experiment Station (WES), and other agencies contracted by WES to determine the impacts of navigation structures (dikes and revetments) on riverine habitats and biota. The rivers studied included the Lower Mississippi, Willamette, Arkansas, and Middle Missouri.

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A review of these studies, as well as other pertinent research, suggests that dikes and revetments have short-term and long-term effects on major riverine ecosystems. Short-term effects may be beneficial and include increases in aquatic habitat diversity and physical stability which, in turn, results in high densities and diversities of fish and macroinvertebrates within the main stem of the river.

Dike fields are intermediate physically, chemically, and biologically to the main channel and backwaters of rivers. Dike fields often support the most diverse fish and macroinvertebrate community of any habitat within the river. But community composition is less stable than backwaters and is dependent upon river stage and water velocity. Moderate and slow-water areas within dike fields provide important spawning and nursery areas for many lotic species of fish within the modified river.

Revetments of broken rock stabilize banks and provide additional hard substrate for colonization by dense populations of invertebrates. Interstitial spaces between rocks may provide areas of moderate flow for juvenile and forage fish.

Long-term effects of river training structures may be detrimental to the biotic integrity of the river. Increased water velocity in the thalweg, as a result of the current being forced into the middle of the channel by dikes, results in riverbed degradation and dewatering of backwater areas during low flow. Stabilization of the channel prevents the river from meandering and forming new oxbow lakes, secondary channels, and backwater habitats. Deposition of silt in backwaters and on the downstream side of dikes results in the loss of these habitats in extreme cases. The result, as demonstrated in portions of the Missouri River, is a reduction in water-surface area; loss of islands, chutes, and backwater areas; and the constriction of the river to a single, narrow channel. On the Lower Mississippi River, these effects have not yet been defined.

PREFACE

This report reviews the results of several projects conducted under the Environmental and Water Quality Operational Studies (EWQOS) Program sponsored by the Office, Chief of Engineers (OCE), and managed by the US Army Engineer Waterways Experiment Station (WES). The OCE Technical Monitors for EWQOS were Dr. John Bushman, Mr. Earl Eiker, and Mr. James L. Gottesman. Program Manager of EWQOS was Dr. J. L. Mahloch (WES).

The EWQOS Program provides new and improved technology for the planning, design, construction, and operation of Corps of Engineers projects in an effort to solve selected environmental problems. The projects reviewed here were funded under EWQOS Work Units VA and VIIB and were conducted by the Environmental Laboratory, WES, or other agencies contracted by WES.

The results presented in this report deal with the effects of dikes and revetments on large riverine ecosystems. The review was prepared by the US Fish and Wildlife Service, Iowa Cooperative Fisheries Research Unit and the Department of Animal Ecology, Iowa State University, under Intra-Army Order No. WESRF 83-139, dated 11 January 1983 (modified with Change Order 3, dated 13 March 1984). The report was prepared by Mr. Mark B. Sandheinrich and Dr. Gary J. Atchison. The projects were administered by Dr. C. H. Pennington, WES.

At the time of publication of the report, COL Allen F. Grum, USA, was Director of WES and Dr. Robert W. Whalin was Technical Director.

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CONTENTS

ENVIRONMENTAL EFFECTS OF DIKES AND REVETMENTS ON LARGE RIVERINE SYSTEMS

PART I: INTRODUCTION

Background

1. Beginning in 1978, Environmental and Water Quality Operational Studies (EWQOS) Work Units VA and VIIB, conducted by the Environmental Laboratory, US Army Engineer Waterways Experiment Station (WES), and other agencies contracted by WES, were begun to determine the impacts of navigation structures on riverine habitats. The rivers studied included the Lower Mississippi, Willamette, Arkansas, and Middle Missouri.

2. There is no major river system in the United States that is naturally flowing throughout its entire length. Flow and channel modifications were traditionally made to accomplish objectives such as flood control, bank stabilization, formation and maintenance of a navigation channel, and land reclamation. These objectives were often met at the expense of other, generally more recent, objectives, such as protection of recreational opportunities and enhancement of fish and wildlife habitat. It is the balancing of all of these objectives that forms a major challenge to those agencies now involved in the management of major riverine resources.

3. A wide variety of control structures have been used to obtain river management objectives. Dikes and revetments form the major channel training structures in the Missouri River system below Sioux City, Iowa (Hallberg, Harbough, and Witinok 1979; Funk and Robinson 1974), and are very common on the Mississippi River (Schnick et al. 1982; Wright 1982) and Arkansas River (Sanders et al. 1985). Revetments have also been used extensively to stabilize the banks and channels of the Willamette River (Hjort et al. 1984).

4. For the purposes of this report, dikes are defined as longitudinal structures placed perpendicular to river flow in alluvial waterways to stabilize the navigation channel. Small dikes used on

nonnavigable streams for bank protection are not addressed in this report. Dikes are usually constructed of stone, pile clusters, or pilings with stone fill. Generally dikes are intended to develop a channel with the dimensions and alignments designed to benefit navigation. They are often used along with revetments to develop and stabilize the channel.

5. A dike field consists of a series of two or more dikes in general proximity to each other. Burch et al. (1984) described the function of dike fields as follows:

> Dike fields change river morphology by decreasing the channel width in the vicinity of the dike fields, decreasing the surface area of the waterway, increasing depths through bed degradation, and sometimes shifting the channel position. As the field is realized and/or constricted, the bed is scoured by locally higher velocities. Decreased velocity within the dike field itself leads to accretion of sediment in this area. Usually it is necessary or desirable for engineering reasons to locate dike fields in natural depositional areas, such as on convex sides of bends. This practice often augments the described morphological changes.

6. Revetments are placed on riverbanks where erosion is taking place, commonly on the concave side of bends, parallel to the flow. They are constructed of rock riprap, stone-fill pilings, articulated concrete mattress, and many other materials. Their purposes are to maintain channel alignment and to stabilize banks.

Purpose and Scope

7. The primary objective of this report was to summarize the research conducted on the Lower Mississippi, Willamette, Arkansas, and Middle Missouri Rivers as well as to present findings from other pertinent studies and to draw overall conclusions about the environmental effects of dikes and revetments on waterways.

8. The primary source materials for this review were technical reports from EWQOS that centered on work done on the Lower Mississippi, Arkansas, Willamette, and Middle Missouri Rivers. In addition, the

authors visited and worked with personnel in the resource library of the Upper Mississippi River Conservation Committee, Rock Island, Illinois, to obtain reports on dike research in the Upper Mississippi River. Computer searches were obtained on materials in the US Fish and Wildlife Service Library in Fort Collins, Colorado. The Iowa State University also performed computer searches of Biological Abstracts and Sport Fisheries Abstracts. Pertinent reports were then examined and, if appropriate, were included in this report.

9. The combined use of dikes and revetments has been very effective in modifying the morphology of waterways to meet a certain set of objectives. The resulting changes also greatly affect fish and wildlife habitat. Probably the best example of effective use of dikes and revetments to realign and stabilize a navigation channel is in the Missouri River. Part II gives a case study of the extent to which channelization can alter habitat. (Specific biological effects will be addressed later in the discussions of dike and revetment structures.)

10. Parts III and and IV describe the physical, chemical, and biological characteristics and changes caused by dikes and revetments, respectively, and a general evaluation of the effects of the two types of structures is given in Part V. Part VI is a summary of the literature review.

PART II: MISSOURI RIVER CASE STUDY

11. The Missouri River begins at the confluence of the Gallatin, Jefferson, and Madison Rivers at Three Forks, Montana. The river flows 4,058 km and drains about 1,354,560 sq km of central North America before joining the Mississippi River north of St Louis (Slizeski, Anderson, and Dorough 1982).

12. Prior to 1910 the Missouri River was characteristically broad and meandering, semibraided or braided depending on location and time period. The river underwent many natural changes resulting from recurrent flooding during the late decades of the 19th century and early 20th century (Hallberg, Harbough, and Witinok 1979). Flooding caused the cutting off of meander loops and created oxbow lakes and a straighter, shorter, wider, and more braided river. With these natural changes there was a balance struck between river length and area. As the river shortened it also widened; it changed from meandering to more braided. Between 1890 and 1923, the channel adjacent to Iowa decreased in length by about 7 percent and increased in width by about 7 percent (Hallberg, Harbough, and Witinok 1979). Sinuosity* declined during this time and sandbars were stabilized and converted to islands (Figure 1).

13. After the 1920's, natural processes should have led to a trend of increased meandering with a lengthening and narrowing of the river, especially during periods of lower flows. However, this did not occur in the Missouri River because of insufficient time before many human-induced changes took place within the river.

14. Prior to major human-induced modifications, the river contained many sandbars and islands along with many backwater areas, chutes, and abandoned channels containing standing water for much of the year. Seasonal flow variation enhanced habitat diversity as high flows refilled backwater areas and low flows exposed additional slack water and shallow areas.

15. Human-induced physical modification of the channel began as

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* Sinuosity, a measure of river meandering, is obtained by dividing river miles by linear miles (Hallberg, Harbough, and Witinok 1979).

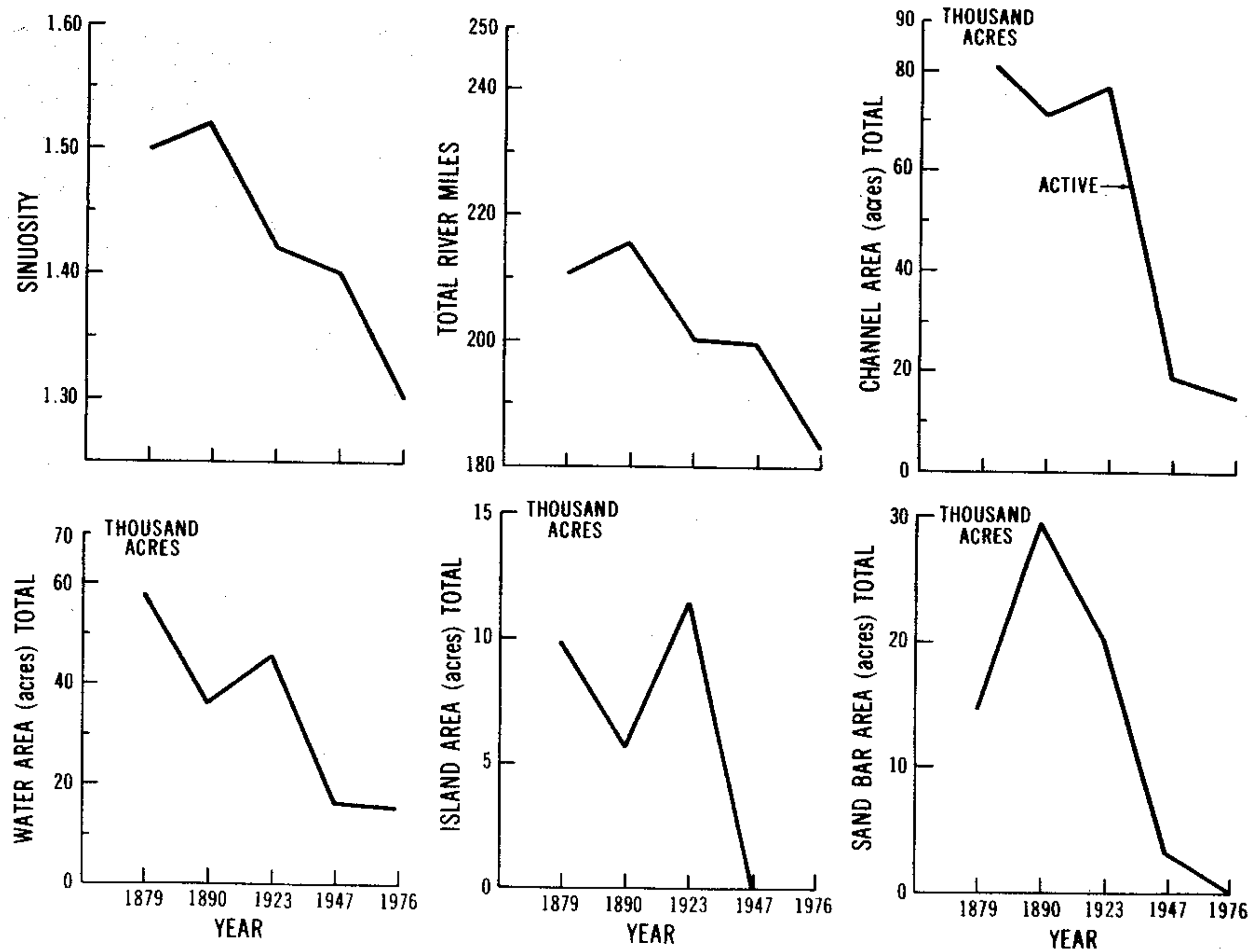


Figure 1. Summary graphs showing changes in channel features in the Missouri River adjacent to Iowa, 1879-1976 (adapted from Hallberg, Harbough, and Witinok 1979)

early as 1832 with the removal of snags to facilitate steamboat travel up the Missouri River (Burke and Robinson 1979). In 1912, Congress authorized the Army Corps of Engineers to stabilize the riverbanks and provide a navigation channel that was 1.8 m (6 ft) deep and 61 m (200 ft) wide from Kansas City to the mouth. The River and Harbor Act of 1927 extended the navigation channel upstream to Sioux City, Iowa. The River and Harbor Act of 1945 increased the depth and width of the channel to 2.7 m (9 ft) and 91.4 m (300 ft), respectively.

16. The formation and maintenance of the navigation channel have been accomplished by building dikes and revetments that concentrate the river flow and force it to scour out a deep channel. In addition, six large multipurpose dams were constructed on the Upper Missouri River from 1940-1964 as part of the Pick-Sloan plan (Fort Peck--1940, Fort Randall--1953, Garrison Dam--1955, Gavins Point--1955, Oahe Dam--1962, and Big Bend Dam--1964). The river is not dammed from Gavins Point Dam at Yankton, South Dakota, to its mouth.

17. River channelization and the construction of dams have resulted in a shorter, narrower channel with smaller fluctuations in flow compared to the premodified river (Funk and Robinson 1974; Hallberg, Harbough, and Witinok 1979). Due primarily to the upstream reservoirs, major floods are now rare, and the control of seasonal discharges prevents some of the fluctuations seen prior to impoundment (Figure 2). For the Iowa-Nebraska portion of the Missouri River, Hallberg, Harbough, and Witinok (1979) reported the following changes between 1923 and 1976: 9 percent (29 km) decrease in river length; 80 percent (25,000 ha) decrease in channel area; 66 percent (12,200 ha) decrease in water area; 99.9 percent (4,700 ha) decrease in island area; and 99.7 percent (8,100 ha) decrease in sandbar area. Similar trends are seen for the Missouri portions of the river (Funk and Robinson 1974). Habitat diversity has been greatly reduced in the process. As a result of decreased sediment load in the water released from the upstream impoundments and the training structures now in place, degradation of the channel bed has become a significant factor for some portions of the river (Sayre and Kennedy 1978) and has contributed to further loss of backwater areas as

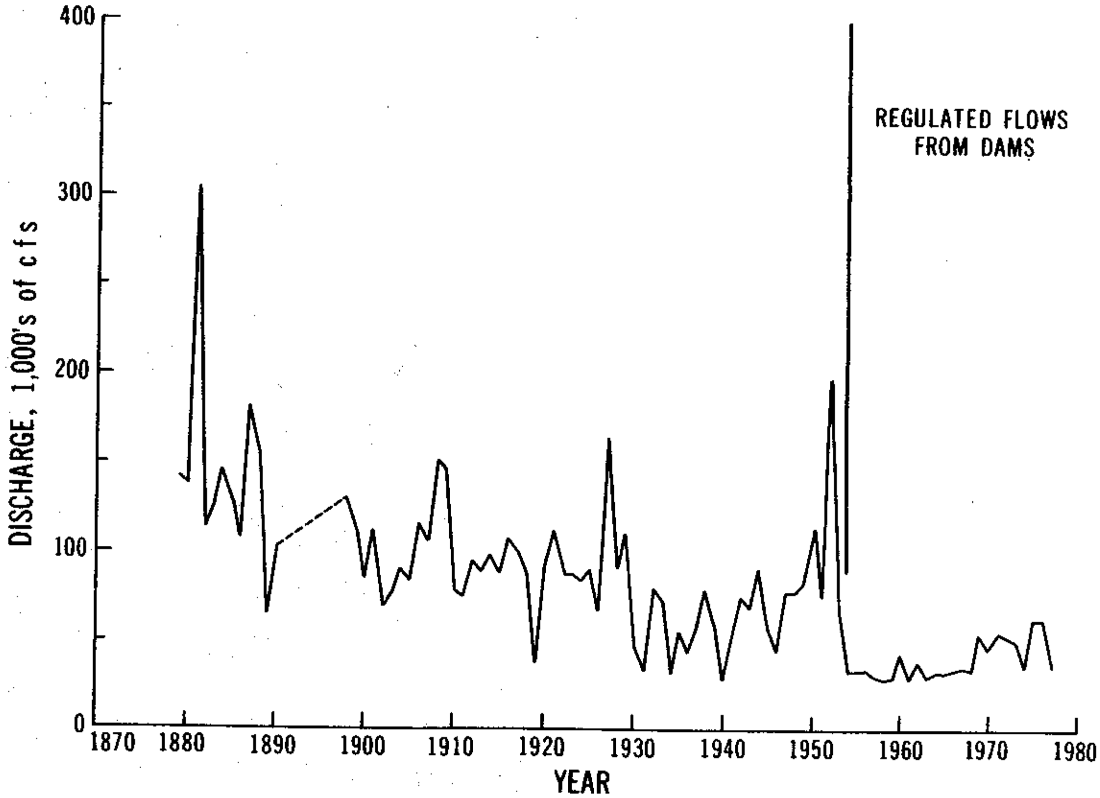


Figure 2. Recurrence characteristics of floods (highest mean monthly discharge per year) on the Missouri River at Sioux City, Iowa, showing the effects of flow regulation from upstream dams (adapted from Hallberg, Harbough, and Witinok 1979)

they lose their connection with the main channel.

18. The balance seen in the natural channel between river length and width (an inverse relationship) was lost once the dams and river-training structures were put in place. Note that all the changes since 1930 are in one direction: decreased length, area, sinuosity, and island and sandbar area (Figure 1). The Missouri River from head of navigation downstream has become a narrow, single, smooth channel with a series of gentle bends and a wellstabilized bank (Hallberg, Harbough, and Witinok 1979). Figure 3 graphically shows one example of the changed river channel, clearly demonstrating loss of habitat for river biota, especially fish. The effects of these habitat losses and the relatively new habitats associated with dikes and revetments will be discussed in detail later in this report.

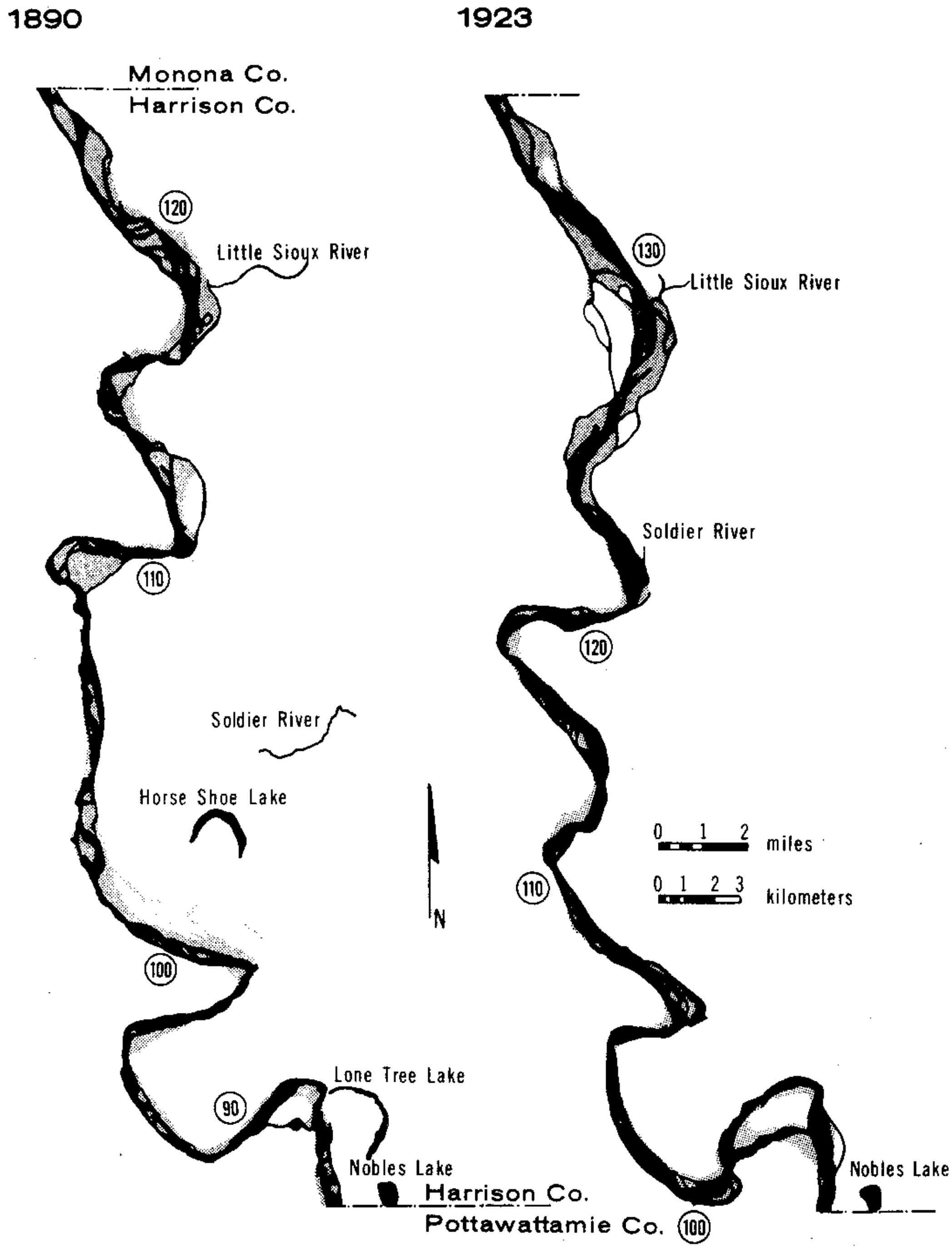


Figure 3. Map showing Missouri River channel features in Harrison County, Iowa. River mile markers are horizontal distances measured along the thalweg and numbered consecutively from the southern border of Iowa. Dark solid areas designate water bodies; stippled areas are sandbars; white areas surrounded by water or sandbars are islands (adapted from Hallberg, Harbough, and Witinok 1979 (Continued)

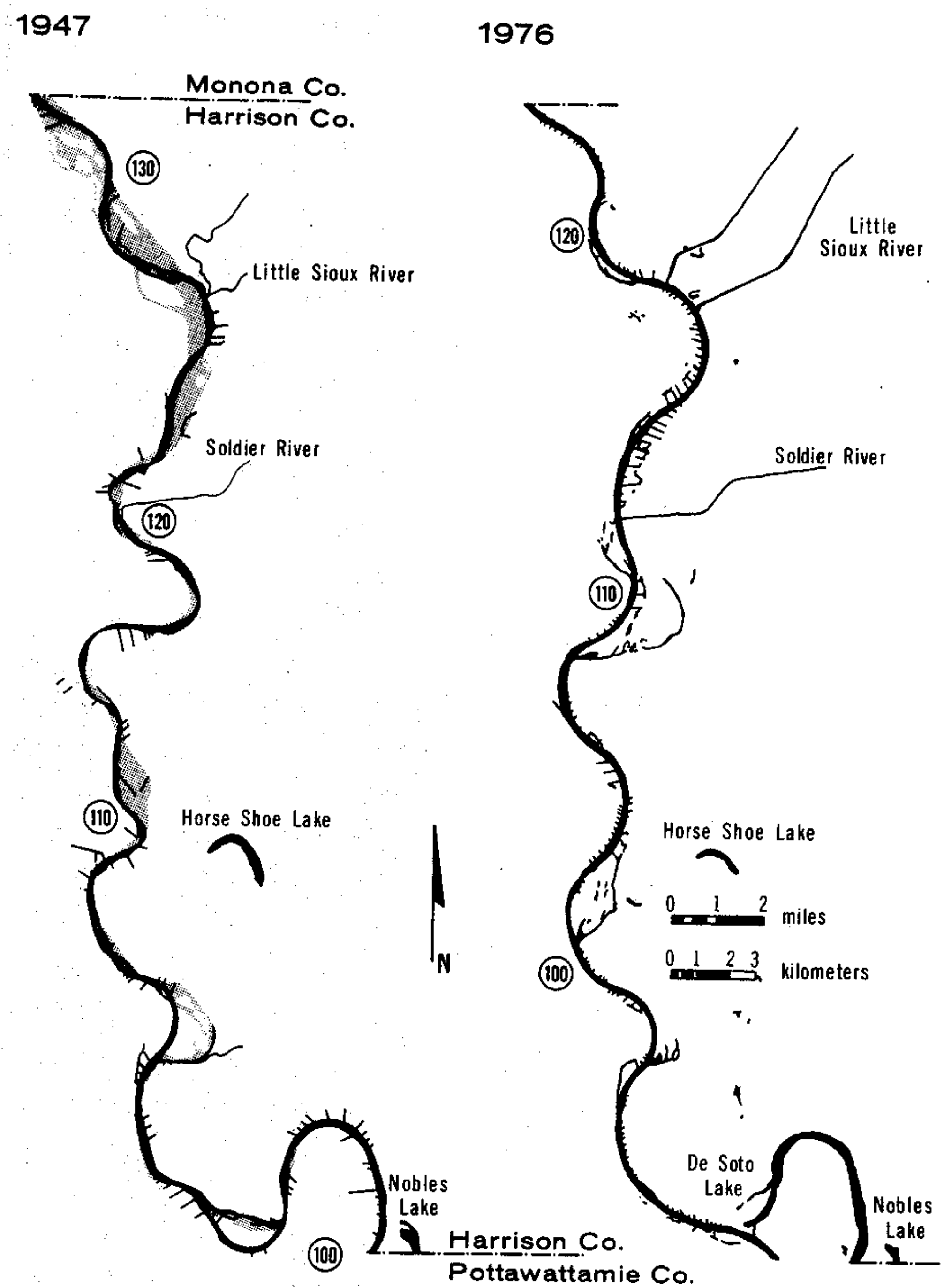


Figure 3. (Concluded)

PART III: DIKE FIELDS

Physical Characteristics

19. During moderate- to low-flow periods, dike fields are physically diverse habitats of standing and/or flowing water consisting of the bank, a shallow to deep channel or pool area adjacent to the bank, the dike structures, and often a large sandbar next to the main channel. During high-flow periods, dikes are overtopped, and habitat within the dike field resembles the main channel. The heterogeneous characteristics of dike fields influence both the density and diversity of aquatic biota associated with these areas and should be considered in any discussion of dike-field impacts on riverine life.

20. Early dikes were often made of single or multiple rows of three-pile clusters usually connected by stringers (Funk and Robinson 1974). Dikes are presently constructed of field stone and quarried rock, though earth-core dikes riprapped with rock are also prevalent. The size of rock used in the construction of dikes and revetments is variable. Burress, Krieger, and Pennington (1982) reported that dikes and revetments on the Upper Missouri River were constructed from rocks 0.2 to 1.0 m in diameter. Specific design and construction practices vary in accordance to different reaches of the river. Dikes constructed since the 1950's on the Mississippi and Missouri rivers are primarily spur dikes (transverse dikes that project perpendicularly from the bank onto the channel or are angled upstream or downstream) (Nunnally and Beverly 1983). Less common are L-head dikes, which are transverse dikes with vanes attached. Several variations (e.g., vane, rootless, notched) of the basic types are also used. Burch et al. (1984) provide detailed descriptions and a discussion of design and environmental features of different dike structures.

21. Deepwater areas, formed by the scouring action of the water current, are typically found adjacent to the upstream and/or downstream side of dikes. These plunge pools enhance the physical diversity of the area near the dike and may provide important cover for several species

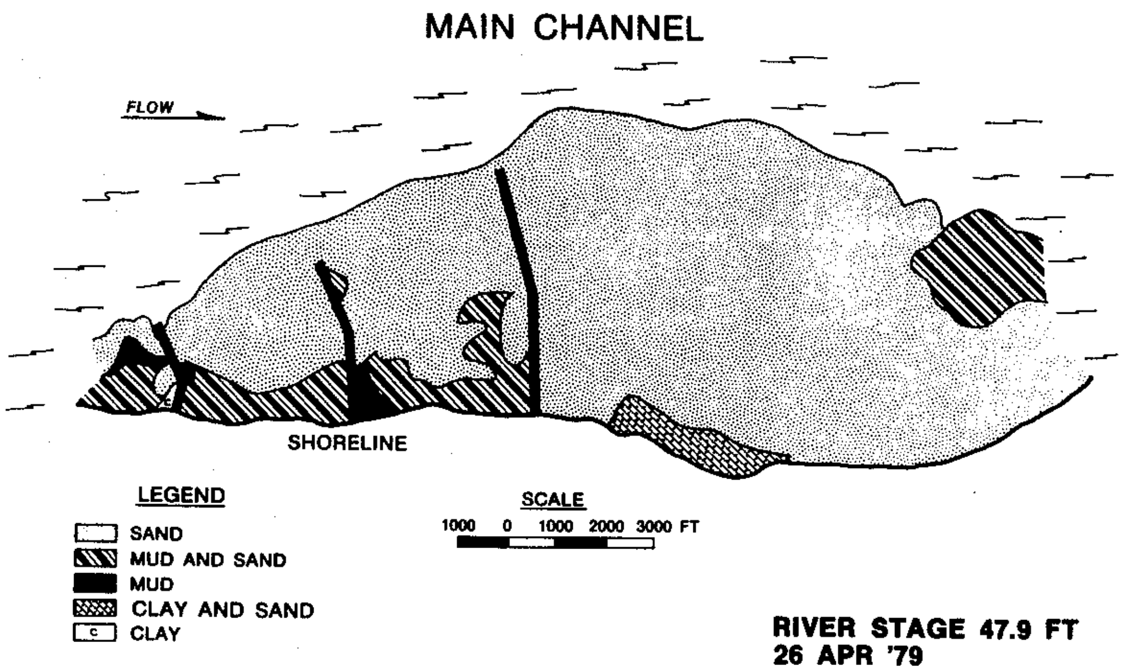
of fish in winter and during periods of low flow. During the winter, Hesse and Newcomb (1982) collected 28 different fish species in scour holes associated with dikes in the Missouri River. Depths of these plunge pools vary. Sanders et al. (1985) found scour holes 6.1 to 10.7 m deep below dikes in the Arkansas River. Plunge pools below spur dikes in the Middle Missouri River were found to vary between 3 and 9.5 m (Atchison et al. 1985). In a study of Iowa dikes in Pools 9 through 19 of the Mississippi River, Pitlo (1981) found that 144 (38.1 percent of those sampled) of these structures had water depths in excess of 6.1 m associated with them (within 30.5 m upstream or downstream of the structure).

22. The specific type of river-regulating structure affects the water depth associated with the structure (Stang and Nickum 1983). Pierce (1980) found that scour holes near emergent spur dikes in the Upper Mississippi River were shallower than those near submerged spur dikes. Depths near submerged spur dikes were usually geater than 2.6 m. Burress, Krieger, and Pennington (1982) found water depths in dike fields of the Missouri River, North Dakota, to range from 0.9 m nearshore to 6.7 m in the area behind stone-filled spur dikes, from 0.3 to 7.9 m at L-head dikes, and from 0.3 to 3.4 m at stone-faced earth-core dikes. Kallemeyn and Novotny (1977) found depths at spur dikes of the Missouri River varied from 1.2 to 5.0 m (mean = 1.6 m); at notched L-head dikes to range between 0.9 to 3.0 m (mean = 1.6 m); and at notched spur dikes to vary from 0.6 to 4.6 m (mean = 2.6 m).

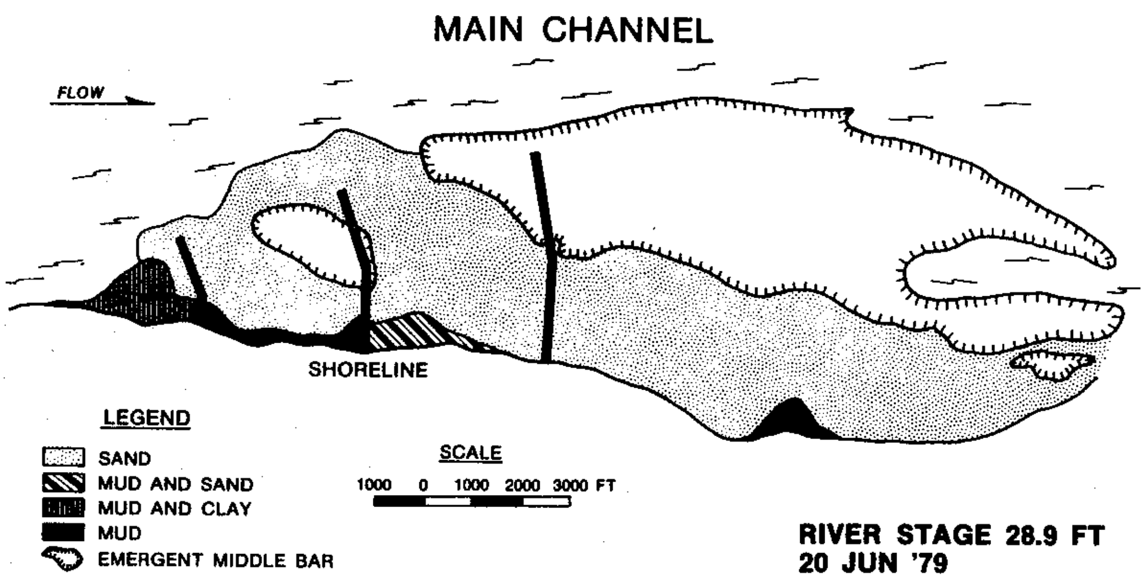
23. Current velocity and its influence on aquatic habitat quality within dike fields is critical in determining faunal-habitat associations and may vary with specific dike structures and placement of these structures adjacent to the channel. Dikes, when not overtopped by the river, provide areas of slow and moderate current within the main stem. Burress, Krieger, and Pennington (1982) reported current velocities at L-head dikes in the Missouri River ranged from no detectable currents in the backwater areas to 1.0 m/sec in the channel at stone-filled spur dikes and 0.4 to 1.0 m/sec at stone-faced earth-core dikes. Hard points (short spurs of rock or stone that extend from bank into channel to

stabilize streambank; see Henderson and Shields 1984 for description) had current velocities that ranged from 0.02 m/sec near the bank to 0.92 m/sec in the channel. Kallemeyn and Novotny (1977) also found the following variable current velocities at different dike structures in the Missouri River. Mean water velocity at spur dikes was 0.9 m/sec, with current speeds ranging from 1.2 m/sec on the upstream side to 0.2 m/sec on the downstream side of the dike. Notched spur dikes had a mean water velocity of 0.4 m/sec (range 0.0 through 1.0 m/sec), and notched L-head dikes had a mean ve-locity of 0.7 m/sec (range 0.4 through 1.2 m/sec). Pitlo (1981) found mean velocities at points 30.5 m above and below spur dikes in the Upper Mississippi River were similar: 0.3 and 0.28 m/sec, respectively.

24. Substrates within dike fields are mosaiclike, consisting of patches of various sediment types arranged as a function of current across the habitat (Beckett et al. 1983). River stage and specific type of channel regulating structure interact with current velocity to influence substrate composition and distributional patterns at a particular site. Changes in substrate composition of dike fields can occur with fluctuations in river stage and scouring action of the current around the dike structure. Sanders et al. (1985) reported that dike-field substrates in the Arkansas River consisted mostly of sand with patches of gravel or silt during periods of high flow when water overtopped the dikes and currents velocities were recorded at 0.3 to 1.2 m/sec. During low-flow periods, the dike fields consisted of a series of lentic pools with no measurable current. Dikes were emergent and fine sand/silt was the predominant substrate type within the pools. Detailed mapping studies of the dike fields of the Lower Mississippi River also indicated a change in substrate composition with river stage (Figure 4 which was taken from Figures 12-14, Beckett et al. 1983). During high flows, scouring occurred and sand dominated the substrate, but with lowered river stage, deposition of sediment occurred and a shift to mud and mud/sand substrates was evident.

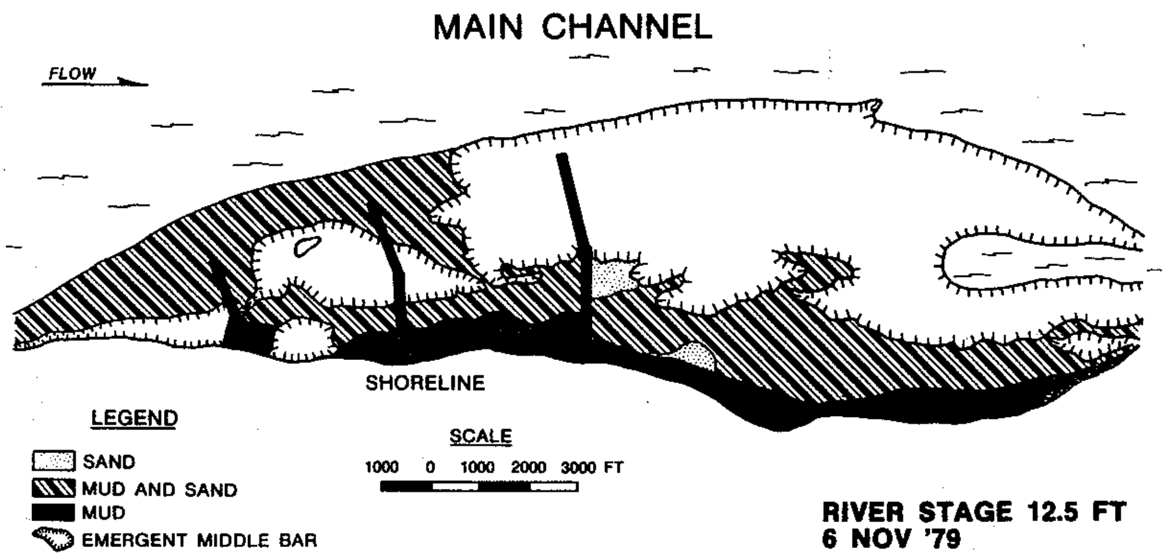


a. High flow



b. Moderate flow

Figure 4. Substrate map of Lower Cracraft Dike Field, Lower Mississippi River, at high, moderate, and low flows (Beckett et al. 1983) (Continued)



c. Low flow

Figure 4. (Concluded)

Chemical Characteristics

25. Water quality conditions within dike fields are of a transitory nature and are related to the presence or absence of current. During lotic periods, dike fields are part of a well-mixed system with values for water quality parameters similar to other habitats in the main channel. Dike fields may become partially or totally separated from the main channel during low-flow intervals, and water quality conditions assume characteristics more similar to abandoned channels.

26. Burress, Krieger, and Pennington (1982) found that water quality conditions were similar in the dike fields and near revetments in the Missouri River below Lake Sakakawea, North Dakota. Large flows in the channel resulted in a rapid exchange of water between dike fields and the main channel. Pronounced diurnal flushing of backwaters, caused by variable water releases for power generation at Garrison Dam, also

contributed to the homogeneity of water quality values from the different habitats. The largest differences in water quality parameters were found in the shallow areas behind the dikes. Surface-water temperatures were occasionally 6 to 7° C higher than those from the nearby channel. A study of the Iowa-Nebraska portion of the Missouri River (Atchison et al. 1985) also suggests that habitats within the main channel of the river constitute a homogeneous chemical environment. Similar values for average temperature, dissolved oxygen, pH, redox potential, turbidity, and specific conductance were found for dike fields and revetments.

27. Large differences in water quality between dike fields and other habitats may occur during periods of low flow when dike fields assume a lentic nature. Sanders et al. (1985) indicated that relatively small differences existed among habitats in the Arkansas River at any given time. But they noted that the characteristics of the system could change drastically over short periods of time. For example, during high flow, temperature and dissolved oxygen concentrations were similar in all habitats. However, stratification was evident during periods of low flow with dissolved oxygen in scour holes of dike fields less than 3 mg/ℓ as compared with 6.4 to 7.4 mg/ℓ at the water surface. No consistent differences among habitats for similar depths were apparent.

28. Dike fields in the Lower Mississippi River also exhibited water quality parameters similar to those in the main channel during high flow. When lentic conditions were observed in the dike fields, water quality values were similar to those observed in the abandoned channels. Lentic conditions in dike fields resulted in thermal and dissolved oxygen stratification within the pools. Lower turbidity and increased water clarity resulted in higher levels of primary production, increased pH, high daytime dissolved oxygen concentrations at the water surface, and low nutrient levels.

Fish Communities

29. Dike fields provide a varied range of depths, substrates, and currents that increase habitat complexity and affect fish distributions

and community diversity. The fish communities associated with dikes are diverse and may harbor more species than any other habitat within the main channel. In the Lower Mississippi River, Pennington, Baker, and Bond (1983) captured the greatest number of species in the dike fields. Fifty-three species were present in the samples. They attributed this diversity to the wide range of depths, currents, and substrates that provided a variety of microhabitats within the dike field.

30. Studies on the Missouri River, including those by Robinson (1973, 1977, 1980), Jennings (1979), and Hesse and Newcomb (1982), have also emphasized the large number of fish species associated with dike structures. Burress, Krieger, and Pennington (1982) compared fish communities of altered and unaltered habitats of the Missouri River in North Dakota. Dike fields had the most diverse fish community of all habitats sampled. Twenty-four species were collected. The diversity of dike field fish communities was in part attributed to the greater efficiency of collecting fish with seines and gill nets in areas with shallow shoreline waters and little or no current, and to the presence of more diverse and sheltered habitats.

31. River stage, current speed, and type of dike and its placement within the channel all affect the composition and abundance of fish populations. Pitlo (1981) found that structures located on concave river bends had significantly higher catch-per-unit-effort and species numbers than those on convex river bends. He concluded that water depth over each structure and location of the structure in relation to the thalweg were the two most important physical characteristics affecting fish populations. Burress, Krieger, and Pennington (1982) found that L-head dikes had a higher percentage of juvenile game fish, species diversity, and fish abundance than did spur dikes, earth-core dikes, or hard points. Jennings (1979) stated that L-head dikes were better than dikeless main-channel border habitat, but that L-head dikes provided only marginal habitat for fish. Sturgeon, buffalo, walleye, and sauger* were more abundant at notched spur dikes, but paddlefish and freshwater drum

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* Scientific names for fish are presented in Appendix A.

were more common near unnotched dikes (Smith et al. 1982). Kallemeyn and Novotny (1977) captured significantly greater numbers of fish from notched spur dikes than from spur dikes or notched L-head dikes in the Missouri River. But Robinson (1980) conducted a study in eight slack-water dike pools in the Missouri River and found no single type of dike or dike modification significantly better for fish than another.

32. The composition of the catch at specific dike structures within large drainage basins, such as the Mississippi River drainage (which includes, among others, the Missouri River), is variable and related to the zoogeography and local abundances of individual species. In the Middle Missouri River, Atchison et al. (1985) found goldeye, gizzard shad, river carpsucker, flathead catfish, common carp, and channel catfish to be the most common species captured with hoop nets and electrofishing gear in dike fields. Goldeye, river carpsucker, common carp, freshwater drum, smallmouth and largemouth buffalo, northern pike, and channel catfish accounted for 98.6 percent of all fish captured by Hesse and Newcomb (1982) from scour holes at the ends of spur dikes in the Nebraska portion of the Missouri River. Kallemeyn and Novotny (1977) reported that channel catfish, common carp, and river carpsucker comprised approximately 70 percent of the catch from channel modification structures in the Missouri portion of the river. In general, commercially harvested fish are more abundant in dike fields than are game species (Pitlo 1981).

33. In the Mississippi River, researchers of Environmental Science and Engineering, Inc. (1982), listed carp, gizzard shad, smallmouth buffalo, white bass, and channel catfish as comprising 75.6 percent of the catch in pooled areas of the upper river. Redhorse spp., carpsucker spp., mooneye, and shovelnose sturgeon were the most prevalent fishes found by Pitlo (1981) along Upper Mississippi River spur dikes. Smith et al. (1982) reported that 85 percent of the catch from dikes in the Middle Mississippi River (river mile 95 to 115) was comprised of gizzard shad, common carp, river carpsucker, freshwater drum, shortnose gar, emerald shiner, and flathead catfish.

34. Several researchers have reported that many species exhibit a

"preference" for spur-dike habitat over other habitats and some species may be associated specifically with dike structures. Robinson (1977) reported that flathead catfish, blue sucker, white bass, and skipjack herring preferred the fast, deep water near dikes. Spur-dike habitat has been found to be of primary importance to flathead catfish, common carp, and golden redhorse (Mississippi River Work Unit 1978). Other studies have indicated that longnose gar and shorthead redhorse prefer dikes to either riprap or sand habitats (Mississippi River Work Unit 1980). Kallemeyn and Novotny (1977) reported that johnny darters prefer spur-dike habitat and gizzard shad prefer notched spur dikes.

35. Burress, Krieger, and Pennington (1982) found six species unique to dike-field habitats of the Missouri River. Present only in the dike fields were the Mississippi silvery minnow, bigmouth buffalo, spottail shiner, bluntnose shiner, fathead minnow, and smallmouth bass. Pennington et al. (1980) found ten species unique to dike fields in the Lower Mississippi River: stoneroller, steelcolor shiner, express minnow, pugnose minnow, spotfin shiner, creek chub, black buffalo, blackstripe topminnow, longear sunfish, and spotted bass.

36. Fish communities associated with dikes are structured primarily by current velocity. In the Arkansas River, Sanders et al. (1985) found that during periods of high discharge, the fish communities of dike fields were distinct from those of other habitats and were comprised of larger more streamlined or bottom-oriented species including channel catfish, flathead catfish, freshwater drum, blue catfish, highfin carpsucker, gars, and river carpsuckers. During seasons of low flow and lentic conditions, the fish communities of these same dike fields were dominated by bluegill, gizzard shad, longear sunfish, white crappie, minnows, silversides, and gars.

37. In the Upper Mississippi River, Bertrand (1971) and Pierce (1980) collected a greater number of fish in the vicinity of emergent spur dikes, which formed large still-water areas, than around submerged spur dikes, which did not form such areas. Lentic fish species such as largemouth bass, bluegill, crappies, pumpkinseed, and orangespotted sunfish were found.

38. At low river stages, dike pools bordered by middle bars were formed in the Lower Mississippi River (Nailon and Pennington 1984). Three generalized fish communities were present. The lentic community, consisting of fish present primarily in pooled habitats, included shortnose gar, American eel, skipjack herring, common carp, gizzard shad, paddlefish, striped bass, sunfishes, sauger, and striped mullet. The shallow-water community on either side of the dike field sandbar included cyprinids, clupeids, and atherinids. Flathead catfish, blue catfish, and blue sucker represented a large portion of the lotic community.

39. Dike fields also support diverse ichthyoplankton communities. Schramm and Pennington (1981) found dike fields in the Lower Mississippi River had relatively low densities of larval fish but a high diversity of taxa. Larval fish were captured from 10 families: Clupeidae, Hiodontidae, Cyprinidae, Catostomidae, Percichthyidae, Centrarchidae, Percidae, Sciaenidae, Atherinidae, and Lepisosteidae. Taxa collected in lentic habitats of the river (abandoned channel and oxbow lake) as well as the lotic main-channel habitats (main channel, permanent secondary channel, temporary secondary channel) were all represented in the dike field, indicating the heterogeneity of dike fields.

40. Conner, Pennington, and Bosley (1983) sampled ichthyoplankton in the Lower Mississippi River to assess the relative importance of dike fields and revetted banks to planktonic fish larvae and to characterize the seasonal changes in local distribution of ichthyoplankton within a dike field. They reported that collections from dike fields and revetments contained larval fish species not found in the abandoned channel. Collections from dike fields made in the spring (April through June) during moderate to high river stages showed that larval fish diversity was high and abundance greater in samples from open water than those from nearshore. Under low-water conditions, the dike field ichthyoplankton was actually two communities. Slack-water pools formed in the dike fields on the inside of the middle bars were populated by larval fishes typical of backwater habitats (primarily shads, bluegill, and inland silversides). The ichthyoplankton community on the river side of

the middle bar was similar to that of the main channel.

41. Atchison et al. (1985) concluded that dike fields were important habitats for larval and juvenile fish, and had a higher abundance of larvae than midchannel sites. Small pools formed by dikes may provide habitat for species that require slower water velocities when spawning or for those species that probably were historically plentiful around sandbars of the braided premodified Missouri River.

Macroinvertebrate Communities

42. Macroinvertebrate distribution within major river systems is largely a function of current and substrate condition. As previously mentioned, bottom substrates of dike fields are mosaiclike, consisting of patches of various sediment types arranged as a function of current across the habitat (Beckett et al. 1983). The distributions of benthic macroinvertebrates parallel this sediment pattern. Beckett et al. (1983) found that sand and gravel substrates in dike fields of the Lower Mississippi River were colonized by the Asiatic clam (***Corbicula fluminea***) and the sand-dwelling chironomids ***Robackia claviger*** and ***Chernovskiia orbicus*** (Diptera). ***Limnodrilus*** spp. (Oligochaeta) and ***Chironomus*** sp. (Diptera) dominated mud substrates. Clay substrates were colonized by burrowing mayflies, ***Pentagenia vittigera*** and ***Tortopus incertus***. The authors noted that the macroinvertebrate community closely reflected shifts from erosional (sand) to depositional (mud-silt) substrates as a result of reduced flow. They concluded that dike fields are biotically and physically heterogeneous at moderate and low flows and support dense and diverse benthic macroinvertebrate populations.

43. Burress, Krieger, and Pennington (1982) found no differences in the number of embenthic taxa (those macroinvertebrates burrowing into the sediments or submerged structure) among various habitat types of the Missouri River. But they did note that the highest density of invertebrates occurred at dike fields with extensive backwater areas. Oligochaetes and dipteran larvae constituted 96.2 percent of the benthic

samples, and highest densities of these organisms occurred in areas with mud and mud/fine sand substrates.

44. Benthic macroinvertebrate densities and community composition fluctuate with discharge in the Arkansas River (Sanders et al. 1985). Dike-field habitats, during periods of high discharge, are characterized by high to moderate currents, varying substrate types, and a relatively sparse benthic macroinvertebrate community dominated by tubificid worms (Oligochaeta) and chironomid larvae ***Tanypus stellatus***, ***Coelotanypus*** sp., and ***Polypedilum illiooense***. Physical conditions were greatly altered by reduced discharge. When no detectable current was evident, bottom substrates consisted of silt, and dense macroinvertebrate populations were dominated by tubificid oligochaetes and larval chironomids represented principally by ***Polypedilum hatterale***, ***Cryptochironomus*** sp., ***Tanypus stellatus***, and ***Chironomus*** sp. Other groups which were relatively rare during high discharge became numerically important, including naidid worms (Oligochaeta), Chaoboridae (Diptera), and ***Hexagenia*** spp. (Ephemeroptera).

45. Dike structures provide a hard stable substrate that is densely colonized by epibenthic macroinvertebrates (occurring on but not burrowing into sediments or submerged objects). Mathis, Bingham, and Sanders (1982) found that the mean density of macroinvertebrates on dike structures in the Lower Mississippi River was 102,000 individuals/m^2 of dike surface area. This was more than 14 times the mean number of macroinvertebrates found by Beckett, Bingham, and Sanders (1983) in the mud substrates of the abandoned channel, which had supported the highest densities of embenthic invertebrates of all habitats sampled in the Lower Mississippi River. Hall (1982) did a prenotching study of aquatic macroinvertebrates associated with dikes in the Upper Mississippi River. Basket samplers placed on dikes yielded almost 27 times the number of macroinvertebrates as did Ponar grabs from sand substrates near the dikes.

46. Current-swept rocks of dikes, revetments, and hard points also supported more kinds and greater numbers of macroinvertebrates per unit area than bottom substrates in studies of main stem habitats of the

Missouri River (Burress, Krieger, and Pennington 1982; Atchison et al. 1985) and Arkansas River (Sanders et al. 1985). Beckett and Pennington (1985) suggested that high macroinvertebrate densities on dikes were due to two factors: (a) colonization of the rock surfaces by dense populations of epibenthic organisms and (b) the three-dimensional aspects of dike structures, which allowed invertebrates on the dikes to colonize the rocks deep into the interior of the dike.

47. Macroinvertebrate communities of dike structures are dominated by net-spinning caddisflies (primarily *Hydropsyche* spp.) and tube-building chironomids. Current speed affects species composition and number of individuals inhabiting these areas. Burress, Krieger, and Pennington (1982) reported that dipterans and trichopterans dominated (60 percent and 24 percent, respectively) invertebrate rock fauna samples from the Missouri River. The number of dipterans, trichopterans, and ephemeropterans increased steadily with current velocity. Approximately 27 percent of the organisms collected from dikes and revetments were taken at current velocities of 0 to 40 cm/sec, whereas almost 73 percent of the organisms were taken at current velocities of 41 to 70 cm/sec. Sanders et al. (1985) noted that dike fields in the Arkansas River exposed to moderate currents were characterized by a lotic assemblage of macroinvertebrates dominated by filter-feeding *Hydropsyche orris* and *Cheomatopsyche* spp. (Trichoptera). Dike fields exposed to no current were characterized by a lentic assemblage dominated by polycentropodid caddisflies and amphipods. A similar relationship between current and community composition was observed in the Ohio River by Beckett and Miller (1982).

PART IV: REVETMENTS

Physical Characteristics

48. Revetments are bank-stabilization structures constructed with stone riprap, broken asphalt pavement, articulated concrete mattress, and similar erosion resistant materials. Burress, Krieger, and Pennington (1982) and Atchison et al. (1985) reported that revetments on the Missouri River in North Dakota and Iowa were composed of irregularly shaped broken rock and field stone 0.05 to 1.0 m in diameter. Revetments on the Arkansas River, Arkansas (Sanders et al. 1985), and Willamette River, Oregon (Hjort et al. 1984) were constructed of similar material. Revetments on the Lower Mississippi River (river mile 480 to 530) consist of articulated concrete mattress with riprap or asphalt on the upper bank and isolated areas of sand and sand/silt overlying the revetment (Cobb and Clark 1981; Miller 1981). Numerous interstices are present between the riprap and concrete slabs.

49. Revetted banks are stable but physically less diverse than nonrevetted sites. Before placement of the riprap, banks are usually graded, reducing steepness, to a 3H:1V slope (Keown et al. 1977). This gradient limits the area of shallow slow-current habitat near the shoreline. Water velocities at revetments are generally moderate to high and approach speeds found in the main channel. Nonrevetted banks are subject to erosion and sloughing but often constitute a physically diverse area with extensive shallow-water areas. Burress, Krieger, and Pennington (1982) found that substrates at two nonrevetted banks in the Missouri River had substrates ranging from mud to gravel. Revetted banks were free of depositional sediments except for small areas near the upper end of the revetment where sand/silt shoals occurred. Current velocities at the revetments ranged from 0.05 to 1.05 m/sec, and at the nonrevetted banks, the current velocity was 0.02 to 0.88 m/sec. Water depth was 0.9 to 7.6 m at the revetments. Atchison et al. (1985) reported current velocities of 1.45 to 2.88 m/sec at revetted banks to be similar to velocities found in midchannel of the Missouri River in Iowa.

50. Sanders et al. (1985) reported that two nonrevetted banks sampled on the Arkansas River had steep sloughing banks and considerable amounts of underwater structure in the form of fallen trees and brush. Substrates were predominantly sand and clay with silt and leaf litter in backwater areas. Depths along the nonrevetted banks were 1.8 to 6.1 m, and current velocities ranged from 0.6 to 1.2 m/sec during June. Revetted banks had substrates that consisted entirely of riprap with depths of 1.8 to 4.6 m. Currents were similar to nonrevetted sites with velocities of 0.9 to 1.5 m/sec.

51. Revetments along the Lower Mississippi River were also found to have substrates consisting primarily of the revetting material, but isolated pockets of sand and sand/silt overlaying the revetments were also found (Pennington, Baker, and Potter 1983). Current speeds over the revetments were often greater than 0.9 m/sec. Unmodified banks sampled in the same study varied from fine sand to hard clay and mud. Fallen trees were present as a result of bank caving, and current speeds were slower than those found along revetted banks.

52. Hjort et al. (1984) found water velocities at two nonrevetted banks in the Willamette River to be more variable and often faster (0.16 through 1.23 m/sec) than at the revetments where moderate uniform velocities of 0.26 to 0.72 m/sec existed. One of the unmodified banks that was examined had a gentle shoreline gradient with a gravel substrate and extensive shallow-water habitat. Erosion at the other unrevetted bank resulted in a steep irregular bank and limited shallow-water habitat.

Chemical Characteristics

53. Revetments have relatively little effect on water quality adjacent to the structures. Water along revetments is part of a well-mixed system as shown by almost uniform values form dissolved oxygen, pH, average temperature, redox potential, specific conductance, and turbidity between revetted banks and other main-channel habitats in riverine systems (Atchison et al. 1985; Burress, Kreiger, and Pennington 1982; Hjort et al. 1984; Sanders et al. 1985; and Witten and Bulkley

1975). During revetment construction, suspended solids and turbidity initially increase at the site but decrease after construction activity ceases and erosion and bank sloughing is reduced (Henderson and Shields 1984). Removal of riparian vegetation, associated with revetment construction, may result in higher water temperatures and rates of photosynthesis. However, the effects of this removal are less important in streams greater than 30 m wide (Stern and Stern 1980) and may be negligible with reestablishment of vegetative cover. Older revetments may become densely vegetated with a variety of herbs, forbs, and stands of cottonwoods and willows (Cobb and Clark 1981).

Fish Communities

54. Differences in river hydrology, extent and type of human modification (locks and dams, dikes, etc.), and regional differences in ichthyofaunal assemblages make comparison among habitats of major river systems difficult. Fish communities associated with the rigorous environment of revetted banks are typically composed of large, robust species able to withstand the swift current. Pennington et al. (1980) and Pennington, Baker, and Potter (1983) found flathead catfish, channel catfish, blue catfish, freshwater drum, blue sucker, gizzard shad, threadfin shad, and skipjack herring common along revetments in the Lower Mississippi River.

55. In the Missouri River, Hesse, Bliss, and Zuerlein (1982) found the most common fish captured along revetments to be common carp, freshwater drum, channel catfish, flathead catfish, and shorthead redhorse. Kallemeyn and Novotny (1977) reported the catch near revetted banks to include common carp, river carpsucker, shorthead redhorse, goldeye, blue sucker, freshwater drum, smallmouth buffalo, white bass, channel catfish, black crappie, and gizzard shad. Similar results were found by Atchison et al. (1985).

56. Sanders et al. (1985) noted that the composition of the ichthyofauna collected from revetments in the Arkansas River was dependent upon the presence or absence of current. During the spring when a

moderate to strong current (0.6 through 1.12 m/sec) was present, the community was similar to those found associated with revetments in other rivers and included catfishes, river carpsucker, freshwater drum, and white bass. The fish community shifted ruing low-flow periods (July to January) to an assemblage dominated by sunfishes and gizzard shad. Smaller numbers of freshwater drum and channel catfish were captured.

57. High densities of small fish were found at revetments in the Willamette River, Oregon (Hjort et al. 1984). The large abundance of smaller fish may have been a result of the protective shelter and moderate currents provided by the numerous interstices of the riprap. Fish fingerlings have also been observed to utilize the protected habitat of riprap interstices (US Army Engineer District, Seattle 1982).

58. Several authors have reported a preference of several fish species for revetted banks over other habitats within the river. Holzer (1979) found a preference for riprap habitat over sand habitats or spur dikes for smallmouth bass and rock bass. Black crappie, white crappie, yellow bullhead, smallmouth bass, river shiner, and golden shiner were found to prefer rock banks over natural banks (Farabee 1982).

59. Studies are contradictory as to whether revetments have higher or lower species numbers, diversity, and biomass than other habitats within the main-channel border of a river. Atchison et al. (1985) captured more fish and more species with hoop nets and electrofishing along revetted banks than at the more physically diverse and protected dike-field habitats of the Middle Missouri River. Conversely, 24 species were collected in dike fields, but only 13 species were found along revetments of the Missouri River in North Dakota (Burress, Krieger, and Pennington 1982). Paddlefish were the only species unique to revetments. Pennington, Baker, and Potter (1983) stated that, for comparable gears, numerical catch per unit effort was seldom significantly different among habitats in the Lower Mississippi River, but that revetted banks generally had a higher biomass catch per unit effort than other habitats.

60. Differences between unmodified and revetted banks are primarily related to the relative proportion of each species in the community

rather than striking differences in species composition between the two habitats. Burress, Krieger, and Pennington (1982) found similar species diversity and abundance along nonrevetted and revetted banks in the Missouri River. Common carp, sauger, white bass, walleye, and northern pike were predominant in the catch from revetted banks. Common carp, white sucker, and burbot were common at unmodified banks.

61. Pennington, Baker, and Potter (1983) investigated fish populations associated with two revetted and two nonrevetted banks on the Lower Mississippi River. They found similar species numbers in the two habitats, but the relative abundances of the species were different for the two habitats. Common carp, smallmouth buffalo, blue sucker, channel catfish, and river carpsucker comprised more than 50 percent of the biomass at revetted banks but less than 10 percent at nonrevetted sites. In contrast, longnose gar, American eel, bigmouth buffalo, flathead catfish, and freshwater drum made up more than 55 percent of the biomass at nonrevetted banks but only 26 percent at revetments. Species of sport or commercial value were more abundant by weight at revetted banks.

62. Unmodified banks on the Willamette River had greater diversity and species richness but lower densities of fish than revetments (Hjort et al. 1984). The higher species diversity at unmodified banks may be the result of a variety of substrate types and range of water velocities. Major species within the habitat included leopard dace, northern squawfish, chiselmouth, mountain sucker, and largescale sucker. Interstitial areas at the revetted banks provided shelter for high densities of small fish which included northern squawfish, prickly sculpin, largescale sucker, chiselmouth, and redside shiner. Ichthyofaunas of unmodified and revetted banks in the Arkansas River (Sanders et al. 1985) and the Lower Missouri River (Kallemeyn and Novotny 1977) exhibited little differences between the two habitats.

63. Relatively little research has been done to assess the importance of revetted banks as spawning areas and nursery areas for larval fish. Holzer (1979) suggested that riprap serves as a nursery for smallmouth bass, walleye, sauger, crappies, and bluegill. Young-of-the-year channel catfish, flathead catfish, goldeye, and gizzard shad have

been associated with revetted littoral areas (Environmental Science and Engineering, Inc. 1982).

64. Atchison et al. (1985) found the highest abundance of larvae in the main channel of the Missouri River to be at revetments. Freshwater drum, carpsuckers, and common carp dominated the ichthyoplankton community. More than 75 percent of all larval walleye and sauger were collected at revetment sites. Balon (1975) classified walleyes and saugers as lithophils (open-substrate spawners). The rock and gravel revetments may provide preferred spawning substrate for these two species.

65. Larval fish collected at revetted banks in the Lower Mississippi River included members from the families Clupeidae, Hiodontidae, Cyprinidae, Catostomidae, Percicthyidae, Centrachidae, Percidae, Sciaenidae, and Atherinidae (Schramm and Pennington 1981). A similar faunal assemblage was found at nonrevetted banks, with the exception of the absence of Atherinidae. Differences in family abundances occurred between the two habitat types. The data indicated that revetted banks may be an important habitat for larval clupeids, hiodontids, cyprinids, centrachids, and sciaenids. Conner, Pennington, and Bosley (1983) described the larval community as being characterized by high relative abundances of minnows, drum, and carpsuckers, but with herrings being dominant.

Macroinvertebrate Communities

66. The distribution and abundance of macroinvertebrates are determined by current speed, water temperature, substrate, and water quality (Hynes 1970). Zoogeographical and seasonal influences are also important. Nonrevetted locations are subject to bank erosion, which may displace organisms or make microhabitats unsuitable for survival or reproduction (Hjort et al. 1984). Revetments benefit many invertebrate species by stabilizing banks and providing substrate suitable for colonization (Johnson et al. 1974; Menzel and Fierstine 1976; Solomon et al. 1975). In many rivers the placement of rock structures provides new habitat that may not otherwise be available (Burress, Krieger, and

Pennington 1982; Hynes 1970; US Army Engineer District, Seattle 1982). Creation of moderate-flow habitat over riprap induces colonization by epibenthic species that prefer this habitat type (US Army Engineer District, Seattle 1982).

67. Species composition and density of invertebrates on stone revetments is similar to that of dike structures within a river. Several studies have found higher densities and diversities of invertebrates on revetments than on nonrevetted banks. Burress, Krieger, and Pennington (1982) found the macroinvertebrate community at revetments in the Missouri River, North Dakota, to consist primarily of dipterans (60 percent) and trichopterans (28 percent) including *Hydropsyche* and *Neureclipsis*. Epibenthic densities were more than ten times higher than densities of embenthic invertebrates at unrevetted banks. Macroinvertebrates common to revetments were found in the stomach contents of walleye, northern pike, white bass, burbot, and shovelnose sturgeon. Atchison et al. (1985) found 64 different taxa on revetments in the Middle Missouri River, including *Hydra*, *Dero digitata* (Oligochaeta), *Isonychia*, *Stenonema* (Ephemeroptera], and the Hydropsychidae *Potamyia flava*.

68. Hydropsychid caddisflies (*Hydropsyche orris* and *Cheumatopsyche* sp.), polycentropodid caddisflies (*Cyrnellus fraternus*), chironomid larvae (Diptera: Chironomidae), and amphipods were prominent at revetments in the Arkansas River (Sanders et al. 1985). Dike structures had higher densities of invertebrates than revetments but approximately half of the number of taxa. Unrevetted banks samples were characterized by sand sediments and low numbers of embenthic invertebrates dominated by oligochaetes (principally Tubificidae) and amphipods.

69. Revetments in the Willamette River, Oregon, had the highest abundances of macroinvertebrates of any habitat sampled (Hjort et al. 1984). In June, revetments had five times more invertebrates than unmodified banks. Higher invertebrate densities at revetted banks were attributed to reduced water currents and the variety of microhabitats provided by the numerous interstices created by the riprap. Species diversity at the two habitats was comparable, but revetments supported a greater number of benthic invertebrate taxa. The functional groups

represented by invertebrate taxa at the revetments included grazers and scrapers (included genera of Ephemeroptera, Trichoptera, Chironomidae, and the lepidopterid (*Paragyractis*), filter feeders (*Manayunkia*, *Hydropsyche*, and *Cheumatopsyche*), and scavengers (Decapoda, *Pacifastacus*; Amphipoda, *Anisogammarus*). The heterogeneity of unrevetted banks promoted high species diversity and richness, but the ephemeral nature of erosional substrates resulted in habitat degradation and lower densities of organisms than revetments. Fine silt and sand substrates reduce the flow of oxygenated water through the substrate. Trichopterans, gastropods, pelecypods appeared to be adversely affected by erosion at unprotected banks along the Willamette River.

70. In contrast to studies on riprap revetments, Mathis et al. (1981) collected very few epibenthic macroinvertebrates with a Shipek grab from the articulated concrete mattress revetments of the Lower Mississippi River. Field observations during low-flow periods indicated that the habitat may be much more productive of benthic macroinvertebrates than sampling demonstrated. Numerous pelecypod shells, hydropsychid caddisfly cases, and larval chironomid tubes were found. This suggested that the paucity of invertebrates in the samples was due to the inability of the Shipek grab to adequately obtain organisms from the smooth surface of the concrete mat.

PART V: GENERAL EVALUATION

Physical and Chemical Characteristics

71. This section provides an overall evaluation of the short-term and long-term effects of dikes and revetments on the aquatic biota of major river systems. Dikes initially increase habitat diversity within the main channel and the physical and chemical conditions are similar to those of the thalweg (river channel) during high flow and to lentic backwater areas during low flow. Dike fields provide protected nursery and feeding areas during flow for juvenile and adult fish. Several species are characteristically collected only or primarily in association with dike fields within rivers.

72. Stone dikes and revetments may provide suitable substrate (that may not be otherwise available) for bottom-dwelling insects and several substrate-spawning fish species. Revetments stabilize banks and result in greater densities of epibenthic insects than unmodified banks. Fish may use revetments as cover because interstitial areas between rocks offer protected areas of low-flow velocity as a result of riffles created at the surface (US Army Engineer District, Seattle 1982). Revetments should not be subject to short-term fluctuations in invertebrate species abundance and diversity caused by habitat instability as commonly occurs at unmodified banks (Hjort et al. 1984).

73. The long-term impacts of river-training structures are difficult to isolate since they are often used in conjunction with other engineering practices. This is particularly true of the Missouri River where storage reservoirs have reduced sediment load and peak flows downstream, resulting in downstream streambed degradation and other physical changes. Dikes and revetments attempt to constrain rivers to a single narrow channel and divert water from chutes, sloughs, and secondary channels within the river (Rasmussen 1979; Burch et al. 1984). Rates of lateral migration of the channel are reduced, and new backwater areas (sloughs and oxbow lakes) and secondary channels are not formed. River-training structures increase the scouring action of the water in the

channel by forcing greater volumes of water through a narrower space. This results in net degradation of the riverbed and dewatering of backwaters during low flows (Rasmussen 1979; Burch et al. 1984). In addition, reduced current in the off-channel backwaters, along channel margins, and on the downstream side of dikes results in deposition of silt and sometimes the gradual filling-in of these areas. Gradually sloping banks and shallow-water areas nearshore are lost (Morris et al. 1968). These changes decrease water-surface area and habitat diversity within the river. Lubinski et al. (1981) estimated that one-third of the water-surface area in the lower reaches of the Upper Mississippi River, where emergent spur dikes were constructed, has become dry land since 1888. Funk and Robinson (1974) estimated the water-surface area in the lower 800 km (500 miles) of the Missouri River decreased from 49,250 ha (121,700 acres) in 1879 to 24,645 ha (60,900 acres) in 1972. Similar losses have occurred along the Iowa/Nebraska portion of the river (Hallberg, Harbough, and Witinok 1979).

74. Islands within rivers have also been virtually eliminated. Between 1879 and 1954, the surface area of islands in the Lower Missouri River was reduced 98 percent, from 9,882 ha (24,420 acres) to 170 ha (420 acres) (Funk and Robinson 1974). Hallberg, Harbough, and Witinok (1979) showed similar changes in the Middle Missouri River. Chutes and sloughs associated with these islands have been lost. They provided additional habitat diversity and offered protected shallow areas with less current than the main channel.

75. To date, the Lower Mississippi River has not experienced aquatic habitat alteration to the same extent as the Missouri River and Upper Mississippi River. Comparisons of the morphology of the Lower Mississippi River between 1962 and 1976 indicated that losses of secondary channel area due to dikes was offset by increases in sloughs (abandoned channels), chutes, and pools (Nunnally and Beverly 1983). Dike-field sedimentation processes appear to be different on the Lower Mississippi River than on the Missouri. The river's low slope, relatively low-sediment load, and highly variable discharge may result in sedimentation patterns maintaining a condition of dynamic equilibrium (Nunnally

and Beverly 1983). However, this does not suggest that aquatic habitat losses cannot yet occur.

Fish

Species diversity and production

76. River channelization generally results in the loss of habitat variability and, as a consequence, a decrease in fish species diversity and productivity (Funk and Robinson 1974). In the Missouri River, fish are more abundant in the unchannelized reaches than in channelized sections of the river (Schmulbach, Gould, and Groen 1975). Groen and Schmulbach (1978) found catch and harvest rates to be higher in the unchannelized portions of the Missouri River than in the channelized portions.

77. Decreased productivity and diversity in channelized sections of major river systems may be partially the result of the loss of shallow backwater areas and secondary channels. Pflieger (1971) suggested that the complex fish fauna of the Middle Mississippi River was partially due to the presence of numerous quiet backwaters. Backwaters in the unchannelized reaches of the Missouri River comprise a total aquatic surface area that is three times greater per linear kilometer than an equal distance of channelized river (Morris et al. 1968).

78. Studies in several river systems have emphasized the importance of backwaters and secondary channels to fish diversity and production. Ellis, Farabee, and Reynolds (1979) sampled three side channels (equal secondary channels) in the Upper Mississippi River representing three stages of riverine succession. Limnological and fish-community characteristics were compared. Similar species numbers and abundance were found in the three habitats; but forage and rough fish were more abundant in the riverine channel, and panfish and game fish were more abundant in the lacustrine side channels. Ragland (1974) found minnows and small fish were almost six times more abundant in seine collections from side channels than in main-channel borders of the Middle Missouri River. Largemouth bass were found only in side channels. Common carp,

bluegill, shortnose gar, black crappie, white crappie, bowfin, and bigmouth buffalo were abundant in side channels but scarce in the main channel where freshwater drum and sauger were relatively common. He concluded that both the main-channel border and side-channel habitats were important as fish habitat. Other studies on the Middle and Upper Mississippi River have shown that side channels support a wide variety of fish species (Bertrand and Allen 1973; Bertrand and Dunn 1973; Bertrand and Garver 1973).

79. Sanders et al. (1985) found that secondary channels supported as many or more species of fish as any other habitat in the Arkansas River. Physical and biological characteristics were similar to those in side channels described by Ellis, Farabee, and Reynolds (1979). However, relatively few species (nine) were collected by Burress, Krieger, and Pennington (1982) from a chute (equals secondary channel) on the Missouri River. Only 12 species were collected by Pennington et al. (1980) with hoop and trammel nets from a permanent secondary channel that was physically similar to the main channel of the Lower Mississippi River. Sanders et al. (1985) suggested that the differences in numbers of species collected from secondary channels in these studies may have been due to the presence or absence of a strong current.

80. After an extensive literature review, Schramm and Lewis (1974) concluded that extra-channel habitats provide the most favorable areas for the production of aquatic organisms in a riverine ecosystem. Backwaters were noted as being especially important for the production of plankton, an important food source for many fish species.

81. In the Lower Mississippi River, Pennington et al. (1980) and Pennington, Baker, and Bond (1983) recognized three fish communities: the standing-water community, the flowing-water community, and the shallow-water shoreline community. Based upon catch-per-unit effort, fish of the standing-water community were most abundant in abandoned channels and an oxbow lake. Species diversity in abandoned channels was less than in dike fields but higher than other main-stem habitats, including revetments. Gizzard shad, river carpsucker, freshwater drum, common carp and shortnose gar were the five most common fish in the

abandoned channel. Brown bullhead, warmouth, paddlefish, spotted gar were characteristic of this habitat. Pennington et al. (1980) and Pennington, Baker, and Bond (1983) concluded that differences in species composition, relative abundances, and fish length frequencies observed among habitats suggested that dike fields, abandoned channels, temporary secondary channels, oxbow lakes, as well as several other main-stem habitats, were all important in maintaining the diverse ichthyofauna of the river.

82. Atchison et al. (1985) found that abandoned channels in the Middle Missouri River yielded greater species richness and overall greater numbers of fish than dike fields or revetments. As in other studies, centrarchids, shad, common carp, river carpsucker, and bigmouth buffalo were prevalent.

83. Abandoned channels of the Willamette River had the only unique fish community of the habitat studied by Hjort et al. (1984). In spite of low species diversity and numbers, several species were unique to the abandoned channel or were most abundant there. The fish community in the slough was trophically more complex than those of lotic habitats. Species present included the piscivorous largemouth bass, white crappie, and channel catfish; the insectivorous bluegill and warmouth; the omnivorous northern squawfish and common carp, and the herbivorous largescale sucker.

Larval fish

84. Backwaters provide valuable spawning and nursery areas for many species of fish and often harbor communities unique to the river. Oxbows and abandoned channels of the Lower Mississippi River had the most distinctive ichthyoplankton of all habitats sampled by Schramm and Pennington (1981) and Conner, Pennington, and Bosley (1983). However, certain major taxonomic groups were either extremely rare or absent in abandoned channel habitats, but occurred commonly in all main-stem habitats. Shads and sunfishes comprised 99 percent of the catch in backwaters. Larval fish were more abundant in abandoned channels than in main-stem habitats.

85. Scheaffer (1984) estimated that backwater areas were

responsible for up to 90 percent of the juveniles and 70 percent of the larvae in Pool 13 of the Upper Mississippi River. After sampling backwater confluences with the main stem of the river, he concluded that backwaters were important areas for fishes characteristically found there and for main-channel species as well. Ellis, Farabee, and Reynolds (1979) concluded that side channels having low flow in late summer and fall probably served as nursery areas for juvenile fish in the Uppper Mississippi River.

86. In the Missouri River, Atchison et al. (1985) noted that more than half of all larval fish collected in their study were from abandoned channels. The catch-per-unit effort in this habitat was twice that of the dike fields, midchannel, and revetted banks of the river. As in the Lower Mississippi River, sunfishes and gizzard shad were the predominant species of the icthyoplankton community. Persons (1979) reported that at least 15 species of fish spawned in Missouri River backwater areas; the catch in tow nets from backwater areas was more than ten times greater than that found in the main-channel drift reported in other studies. Hergenrader et al. (1982) provided evidence that backwaters serve as nursery areas within the river. Only 0.11 percent of the fish were juveniles in larval fish collections from the main stem of the river; but in backwaters, such as tributary streams, juveniles made up 20 to 35 percent of the collection. Several other studies have stressed the importance of backwaters and marshes as spawning and nursery sites for riverine species in the Missouri River (Kozel and Schmulbach 1976; Kallemeyn and Novotny 1977).

Macroinvertebrates

87. River channelization has also resulted in decreased invertebrate production. Though the main channel has the lowest invertebrate density and diversity of any habitat within the Missouri River, the benthic biomass and diversity of the main channel is higher in unchannelized sections than in channelized sections (McMahon, Wolf, and Diggins 1972; Morris et al. 1968; Nord and Schmulbach 1973). Russell

(1965) estimated the standing crop of invertebrates from habitats in the unchannelized Missouri River to be 1.18 kg/ha, as compared with 0.50 kg/ha for habitats in the channelized river. Wolf, McMahon, and Diggins (1972) found that main-channel habitats of seminatural areas of the Missouri River (unchannelized sections above Sioux City, Iowa, but below main-stem impoundments) had three times the density of organisms of channel habitats in the channelized river.

88. Backwaters support high densities of aquatic organisms and are a major source of invertebrates in riverine ecosystems. Schramm and Lewis (1974) concluded, after an extensive literature review, that physical and chemical conditions in backwaters were more favorable for development of benthic communities than in any other habitat of the Middle Mississippi River. Volesky (1969) estimated that 50 percent or more of the benthic standing crop of the Missouri River originated in the cattail marshes, though these habitats comprise only 15 percent of the river's surface area. Wolf, McMahon, and Diggins (1972) found that cattail marshes had the highest densities of any habitats sampled in the Missouri River and contained up to 18 times more organisms than the main channel of the channelized river. In the Upper Mississippi River, Eckblad, Volden, and Weilgert (1984) found that drift samples from large side channels draining backwater areas had mean numbers of invertebrates that were 10 times larger than samples from the main channel. Scheaffer (1984), in a study of the drift in backwaters and the main channel of Pool 13 of the Upper Mississippi River, estimated that 54 percent of the invertebrates in the river were from backwater areas.

89. Backwaters are dominated by oligochaetes and chironomids (Diptera) inhabiting a substrate composed of silt, mud, sand, and clay. Trichoptera and Ephemeroptera, which are prevalent on dikes and revetments, are absent or present in relatively low numbers. In the Missouri River, Atchison et al. (1985) found that abandoned channels had higher densities of invertebrates but fewer taxa than rock dike and revetment structures of the main channel. The invertebrate community of the abandoned channels also exhibited the greatest taxonomic stability over time.

90. Sanders et al. (1985) reported that oligochaetes, principally Tubificidae, were the dominant group of macroinvertebrates collected in the secondary channels and abandoned channels of the Arkansas River. They comprised 87.9 percent and 58.3 percent, respectively, of the total number of invertebrates collected from the two habitats. As in the Missouri River, invertebrate communities in the abandoned channel were highly productive, stable, and lentic in nature regardless of river stage.

91. In the Lower Mississippi River, abandoned channels consistently supported higher macroinvertebrate densities than natural banks, secondary channels, or dike fields. Approximately 3,000 to 7,500 individuals/m^2 were found in the abandoned channels (Beckett, Bingham, and Sanders 1983). The phantom midge, ***Chaoborus punctipennis*** (Diptera: Chaoboridae), ***Limnodrilus*** (Oligochaeta), and the fingernail clam, ***Sphaerium transversum*** (Pelycepoda) were the dominant taxon. But, unlike the Missouri River study by Atchison et al. (1985), invertebrate densities of the abandoned channels of the Lower Mississippi River were less than those of the dike structures, which supported over 101,000 individuals/m^2 (Mathis, Bingham, and Sanders 1982).

92. The invertebrate community of an abandoned channel in the Willamette River was trophically more complex than communities of lotic habitats (revetments, unmodified bank, secondary channel) in the river (Hjort et al. 1984). Most of the common invertebrates in lotic habitats were herbivorous, with scavengers also found at revetments. The benthic community of the abandoned channel included predators, as well as herbivores and scavengers. Predators in the abandoned channel were Odonata, ***Sialis*** (Megaloptera), ***Procladius*** (Diptera:Chironomidae), Hydracarina (Arachnoidea), and Chaoboridae (Diptera). Scavengers included Turbellaria, ***Helobdella*** (Hirudinea), and ***Asellus*** (Isopoda). Herbivores included ***Dubiraphia*** (Coleoptera), ***Oecetis*** (Trichoptera), ***Caenis*** (Ephemeroptera), ***Gyraulus*** (Gastropoda), and the filter-feeding mayfly, ***Hexagenia***.

PART VI: SUMMARY AND RECOMMENDATIONS

93. Dikes and revetments have short-term and long-term effects on major riverine ecosystems. Short-term effects may be beneficial and include increases in aquatic habitat diversity and physical stability, which in turn result in high densities and diversities of fish and macroinvertebrates within the main stem of the river.

94. Dike fields are heterogeneous habitata and often support the most diverse fish and macroinvertebrate community of any habitat within the river. Community composition is less stable than backwaters and is dependent upon river stage and water velocity. Moderate and slow-water areas within dike fields may provide important spawning and nursery areas for many species of fish.

95. Revetments stabilize banks and provide additional hard substrate for colonization of dense colonies of invertebrates. Interstices between rocks may provide areas of moderate flow for juvenile and forage fish.

96. Long-term effects of river-training structures are difficult to isolate since they are used in conjunction with other engineering practices. Increased water flow in the thalweg, as a result of the current being forced into the middle of the channel by dikes, results in riverbed degradation and dewatering of backwater areas during low flow. Stabilization of the channel prevents the river from meandering and forming new oxbow lakes, secondary channels, and backwater habitats. Deposition of silt in backwaters and on the downstream side of dikes often results in the loss of these as aquatic habitats.

97. The loss of quiet backwater areas is deleterious to the productivity and diversity of the river. Backwaters are responsible for a major portion of the river's macroinvertebrate production and provide valuable spawning and nursery areas for several river species. The fish community is typically comprised of lentic species, including several important game and commercial species, and is unique when compared to main-stem habitats, adding increased faunal diversity to the river.

98. Dike-field sedimentation rates appear to be different on the

Lower Mississippi River than on the Missouri and Upper Mississippi Rivers. Also, the Lower Mississippi River has not experienced aquatic-habitat alteration to the same extent as the Missouri and Upper Mississippi Rivers.

99. Dike fields are areas of considerable physical and biological heterogeneity at moderate and low water flows. These areas are densely colonized by invertebrates and provide a valuable habitat for a diverse community of adult, juvenile, and larval fish species. The authors recommend that dike fields be designed so that they do not become completely silted in.

100. Studies are needed to determine the specific uses of revetments and dikes by fish. For example, the use of plunge pools below dikes as overwintering habitat for fish should be evaluated. Additional studies are needed to obtain a better understanding of dike field sedimentation in relation to dike field design, dike location, and flow hydrology.

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APPENDIX A: SCIENTIFIC AND COMMON NAMES OF FISH

Scientific Name	Common Name
Acipenseridae	Sturgeons
Scaphirhynchus platorynchus	Shovelnose sturgeon
Polydontidae	Paddlefishes
Polyodon spathula	Paddlefish
Lepisosteidae	Gars
Lepisosteus oculatus	Spotted gar
L. Osseus	Longnose gar
L. platostomus	Shortnose gar
Amiidae	Bowfins
Amia calva	Bowfin
Angullidae	Freshwater eels
Anquilla rostrata	American eel
Clupeidae	Herrings
Alosa chrysochloris	Skipjack herring
Dorosoma cepedianum	Gizzard shad
D. petenense	Threadfin shad
Hiodontidae	Mooneyes
Hiodon alosoides	Goldeye
H. terqisus	Mooneye
Esocidae	Pikes
Esox lucius	Northern pike
Cyprinidae	Carps and minnows
Acrocheilus alutaceus	Chiselmouth
Clinostomus elongatus	Redside dace
Cyprinus carpio	Common carp
Hybognathus hayi	Cypress minnow
H. nuchalis	Mississippi silvery minnow
Notemigonus crysoleucas	Golden shiner
Notropis atherinoides	Emerald shiner
N. blennius	River shiner
N. emiliae	Pugnose minnow
N. hudsonius	Spottail shiner
N. simus	Bluntnose shiner
N. spilopterus	Spotfin shiner
N. whipple	Steelcolor shiner
Pimephales promelas	Fathead minnow
Ptychocheilus oregonensis	Northern squawfish
Rhinichthys falcatus	Leopard dace
Catostomidae	Suckers
Carpiodes carpio	River carpsucker
C. velifer	Highfin carpsucker

Catostomidae (Continued)	
Catostomus commersoni	White sucker
C. marocheilus	Largescale sucker
C. platyrhynchus	Mountain sucker
Cycleptus elongatus	Blue sucker
Ictiobus bubalus	Smallmouth buffalo
I. cyprinellus	Bigmouth buffalo
I. niger	Black buffalo
Moxostoma errythrurum	Golden redhorse
M. macrolepidotum	Shorthead redhorse
Ictaluridae	Bullhead catfishes
Ictalurus furcatus	Blue catfish
I. natalis	Yellow bullhead
I. nebulosus	Brown bullhead
I. punctatus	Channel catfish
Pylodictis olivaris	Flathead catfish
Gadidae	Codfishes
Lota lota	Burbot
Cyprinodontidae	Killifishes
Fundulus notatus	Blackstripe topminnow
Atherinidae	Silversides
Menidia beryllina	Inland silverside
Percichthyidae	Termperate bases
Morone chrysops	White bass
M. saxatilis	Striped bass
Centrarchidae	Sunfishes
Ambloplities rupestris	Rock bass
Lepomis gulosis	Warmouth
L. humilis	Orangespotted sunfish
L. macrochirus	Bluegill
L. megalotis	Longear sunfish
Micropterus dolomieui	Smallmouth bass
M. punctulatus	Spotted bass
Pomoxis annularis	White crappie
P. migromaculatus	Black crappie
Percidae	Perches
Etheostoma nigrum	Johnny darter
Stizostedion canadense	Sauger
S. vitreum vitreum	Walleye
Sciaenidae	Drums
Apeodinotus grunniens	Freshwater drum
Mugilidae	Mullets
Mugil cephalus	Striped mullet
Cottidae	Sculpins
Cottus asper	Prickly sculpin